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FIELD DETERMINATION OF DOSE FROM ^{133}Xe IN THE PLUME FROM A PRESSURIZED WATER REACTOR

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Abstract

FIELD DETERMINATION OF DOSE FROM ^{133}Xe IN THE PLUME FROM A PRESSURIZED WATER REACTOR.

A commercially available instrument designed for measuring low-energy gamma radiation has been successfully utilized to monitor the plume from a pressurized water reactor (PWR). The detector consists of a 1/16-in. thick by 5-in. diameter NaI(Tl) crystal optically coupled through a quartz light pipe to a 5-in. multiplier phototube. Pulses from the detector are sorted by use of a single-channel pulse height analyser and read from a linear-log meter. The ratio of counting efficiency to background response $\left(\frac{E}{B}\right)$ was optimized using a sample of the stored gas before release. Response of the instrument is compared with a tissue-equivalent ionization chamber to approximate the external dose to persons in or near the plume. The composition of the gamma-emitting radionuclides in the gas decay tanks is about 99% ^{133}Xe. During release of the gas from the decay tanks there were 3000 μCi/s of ^{133}Xe discharged. The instrument response at a distance of 0.4 mile was six times the background reading. At distances greater than one mile the plume was still easily detectable. Atmosphere stability conditions were neutral with very light wind at the time of the measurements. Gas samples were collected in the field at the boundary of the plant to check calculated atmospheric dispersion estimates. During approximately half the collection period readings above background were observed on the field instrument. The detector system described is applicable for "tracking" the plume from PWRs, and can also be used for estimating the dose to the population for both decay tank discharges and accidental releases.

1. INTRODUCTION

The contribution of nuclear power facilities to population radiation dose is of considerable interest since the industry is growing at a rapid rate and becoming widespread. Assessment of dose from the gaseous route is usually difficult since the radioactivity of continuous discharges is extremely low from pressurized light-water reactors (PWR). The practice at PWR's is to store most gases generated by reactor operation to allow removal of short half-life

radionuclides by decay. The relatively long-lived stored gases are then discharged to the atmosphere occasionally. This paper describes a method for rapidly determining the exposure rate to the population when the principal gamma-ray emitter in discharges is ^{133}Xe.

Most field instruments in use today (GM monitors, ionization chambers, NaI(Tl) detectors) lack the sensitivity for detecting the low levels of gamma radioactivity discharged even during release of stored gases. A field instrument for the detection of low energy radiation (FIDLER) [1], was tested for its feasibility in detecting a plume composed of ^{133}Xe and measuring doses produced by it. Tests were conducted for these purposes and are described below as well as the attempt to correlate instrument readings with ambient ^{133}Xe concentrations contributed by the release.

The test site was at the Connecticut Yankee Nuclear Power Plant (CYNPP) located at Haddam Neck, Connecticut, on the east bank of the Connecticut River. This 590-MWe Westinghouse reactor has operated since July 24, 1967. Most gaseous wastes are stored in a 570 cubic meter surge sphere prior to release at approximately two-month intervals lasting about four hours each. The stored gases are diluted approximately a thousand-fold and discharged at a rate of 33 m^3/sec through a 1.8-m dia., 53-m high stack to the atmosphere. The stack is adjacent to the reactor containment structure of similar height. This aerodynamically affects the plume, producing a downwash effect. The plant is located in a wooded river valley with steeply rising hillsides that channel the wind to a predominantly northwesterly or east-southeasterly direction.

The gases released at CYNPP consist primarily of 10.7-year ^{85}Kr and 5.3-day ^{133}Xe, with relatively small amounts of 12.4-year tritium gas, 5730-year ^{14}C, 9.1-hour ^{135}Xe and 2.26-day ^{133m}Xe. Since ^{85}Kr possesses a 514-keV gamma photon abundance of only 0.43 percent, and the ^{135}Xe is in extremely low concentrations, over 99 percent of plume gamma flux is produced by ^{133}Xe emitting 32-keV cesium K X-rays and 81-keV gamma rays of 46 and 37 percent abundance respectively [2].

2. INSTRUMENTATION

The FIDLER detector is a 1.6-mm thick by 12.7-cm dia. NaI(Tl) crystal optically coupled through a quartz light pipe to a 12.7-cm dia. multiplier phototube. It is an integral line type 20SHB63K/5-2 manufactured by the Harshaw Chemical Company. The detector is connected to an Eberline Instrument Corporation Model PRM-5-3, battery powered pulse rate meter. This instrument has a linear log readout meter and three single channels for energy discrimination. Each channel is independent but only one can be used at a time. The window widths were preset at 50 percent of the baseline energy to reduce background and to permit most of the photopeak to be counted. The meter was modified to permit a Texas Instrument Servo/Writer #2, Model #PSO(W/6A), strip chart recorder to plot the readings continuously. A portable generator powered the recorder and a Cornelius Model 32-R-300 air compressor was connected to a 34-liter cylinder for collecting samples of ambient ^{133}Xe. The cylinders can contain up to 0.9 m^3 of gas under pressure.

The FIDLER was calibrated by reference to a tissue equivalent ionization chamber with a Shonka [3] electrometer. The ionization chamber is a 16.5-liter sphere with 6-mm thick plastic walls containing a neon-ethylene-ethane-nitrogen gas mixture (750 torr at 15°C). The vibrating reed electrometer has a design sensitivity of 0.32 mV per sec per μR/hr, compared to the value measured with a National Bureau of Standards radium standard of 0.35 mV per sec per μR per hr.

The calibration source was a 3-cc glass vial containing 415 μCi of ^{133}Xe. Measurements of dose rate versus distance between the source and the center of the ionization chamber were made using the Shonka electrometer. These dose rates were compared to FIDLER readings at three source distances. Linearity of net counts as a function of μR/hr was observed at the three locations. A FIDLER count of 15 000 counts/min was found to be equivalent to 1 μR/hr on the ionization chamber. This value accounts only for the gamma-ray emissions from ^{133}Xe. The maximum beta particle energy of ^{133}Xe is 346 keV and will also contribute to the skin exposure. These calculations are not included in this paper but the skin dose is approximately 5 μR/hr for the concentration levels observed [4].

3. GAS DISCHARGE LEVELS

A sample of the waste surge sphere taken prior to the release indicated that the concentration of gamma-emitting radionuclides were: ^{85}Kr 0.14 μCi/cc, ^{133m}Xe 0.0015 μCi/cc, and ^{133}Xe 1.33 μCi/cc. The ^{133}Xe activity release rate was 2480 μCi/sec during the first two hours of the study and 4280 μCi/sec during the last hour.

This was a special release through the courtesy of Connecticut Yankee and was about three times higher than normal because the plant was preparing for refueling.

A 100-liter aliquot of each air sample was processed through a 180-gram, Columbia 6 GC, charcoal bed immersed in a dry ice and acetone refrigerant bath at -76°C. The charcoal, sealed in a gas-tight container, was analyzed for 100 minutes by gamma-ray spectrometry using a 10-cm NaI(Tl) crystal.

4. FIELD SAMPLING OPERATIONS

During the fall of 1970, the feasibility of the FIDLER for plume detection was determined and in April 1971 a field study at CYNPP was performed. To obtain the maximum possible levels in the field, the preferred meteorological conditions should be neutral with light winds. The weather conditions at the time of the field study were category "C" [5] or slightly unstable. Strong cold advection with overcast skies, fast winds, and very irregular terrain dictate the category selection. Average wind velocities over 10-minute intervals varied from 2.2 to 8 m/sec with gusts to 11 m/sec, measured by the plant's meteorological equipment. The temperature at the time of sampling was 8°C.

Three FIDLER's were used to locate the plume centerline at ground level. Before the release and frequently thereafter, ^{133}Ba (emitting Cs X-rays and 80-keV gamma rays similar to ^{133}Xe) was used to assure that the instrument channels were aligned properly for energy and optimized for sensitivity. The background level at the 81-keV peak

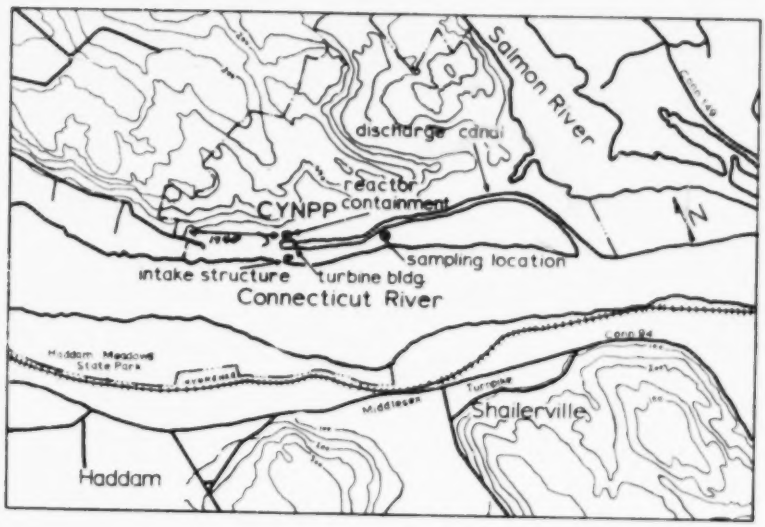

Fig. 1. Connecticut Yankee Nuclear Power Plant (CYNPP) area map.

was approximately 2500 cpm. During release, three individuals made readings across a 150-meter arc at the 0.6-km distance to locate the area of highest readings. When the optimum sampling point was established the air sampling equipment and recorder were started. Figure 1 shows the topography and the location of the plant, plant boundary and sampling station. The maximum FIDLER count rate was obtained 0.6 km east-southeast of the stack on plant property near a steep slope (Figure 1). This distance corresponds to the closest distance to the plant boundary from the stack, which however is in the opposite direction.

5. RESULTS AND DISCUSSION

Table I shows the sample collection interval, duration in plume, total net integrated FIDLER counts during the entire sampling periods and the ambient ^{133}Xe concentration levels obtained from analysis of

TABLE I. MEASURED EXPOSURE RATES ATTRIBUTED TO PLUME RADIOACTIVITY

Sample No.	Integrated net cpm	Time-normalized cpm	Integrated exposure rate μR/hr	Time-normalized exposure rate μR/hr
1	670	1610	0.045	0.110
2	2070	2070	0.140	0.140
3	1440	1490	0.096	0.100
4	990	2100	0.066	0.140
Average	1294	1818	0.086	0.130

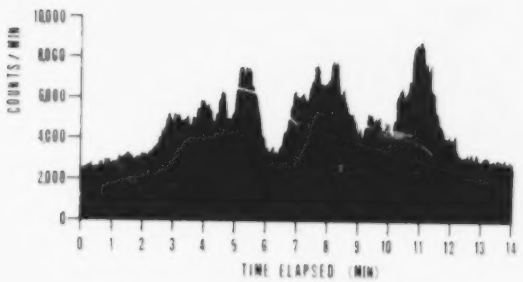

Fig.2. Strip chart readout from FIDLER probe.

the samples at the laboratory. The total net counts over the sampling period were determined by obtaining from the strip chart (Figure 2) the mean reading during each 10-second interval and averaging the values for each minute. Four air samples were collected over a three-hour period at the location shown in Figure 1. FIDLER readings varied from background of 2500 to nearly 9000 cpm. The background of 2500 cpm was subtracted to obtain net values over the sampling interval.

The minimum detectable concentration of ^{133}Xe, using the FIDLER instrument, is less than 2×10^{-8} μCi/cc which represents about a factor of 10 less than the allowable ambient concentration for the general population (10 CFR-20) [6] on a continuous basis. It must be remembered that this level only occurs in the plume at 0.6 km from the stack for about 24 hours during the year.

The highest whole-body exposure level integrated over the sampling was 0.14 μR/hr during the collection of sample number two. The average level during the time of plume detection (2.3 hrs) was 0.086 μR/hr, as given in Table I. The integrated net counts per minute (cpm) show the average over the collection period. The time-normalized cpm are only during times of FIDLER readings above background. Any FIDLER response above background during the collection interval was considered within the plume even though the counts recorded could have been received from the plume passing overhead or to the side of the compressor. Refer to Figure 2 which shows the chart readout from the FIDLER. Sample numbers 1 and 4 were most affected, since instrument readings above background were obtained only approximately 45 percent of the time of collection. The average exposure rates by these two methods give values of 0.086 and 0.12 μR/hr. The latter value represents the level that would be expected if one remained at least partially in the plume the entire time. The highest ^{133}Xe concentration occurred in the second sample which, according to the FIDLER recorder, was in the plume the entire 35 minutes of sampling, and also had the highest net counts on the field instruments.

Figure 3 shows the total integrated FIDLER counts over the gas collection period in the field and compares this to the concentration obtained in the samples. On the basis of this it appears an estimate of ambient ^{133}Xe concentration can be obtained from the instrument response in the field, if integrated over the total sampling time.

5

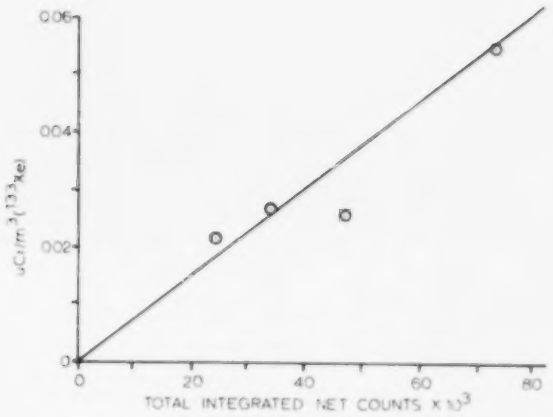

Fig. 3. Concentration (^{133}Xe) versus FIDLER count rate.

TABLE II. FIDLER RESULTS AND MEASURED ^{133}Xe CONCENTRATIONS

Sample No.	Collection Period min	Duration in Plume min	Integrated Total Net Counts 10^3	^{133}Xe Concentration $\mu Ci/m^3$
1	36	15	24.0	0.0217 ± 0.0005 [a]
2	35	35	72.5	0.0547 ± 0.0007
3	32	31	46.1	0.0257 ± 0.0009
4	34	16	33.7	0.0266 ± 0.0005

[a] 2σ counting error.

TABLE III. OBSERVED AND CALCULATED ATMOSPHERIC DISPERSION OF ^{133}Xe (sec/m^3)

Sample No.	Observed	Calculated	Observed / Calculated
1	8.8×10^{-6}	1.4×10^{-5}	0.63
2	2.2×10^{-5}	9.0×10^{-6}	2.4
3	6.8×10^{-6}	7.8×10^{-6}	0.87
4	6.2×10^{-6}	8.3×10^{-6}	0.75

Agreement between measured and calculated dispersion levels is good, as shown in Table I. Calculations for the plume rise were those recommended by the ASME Guide [7] and the dispersion estimates are based on equations by Pasquill and modified by Gifford [5]. (Equations and the parameters used to make these estimates are presented in the Appendix.) The estimations were made for location on the plume centerline. The effects of building downwash and highly irregular terrain were not taken into account. However, the effect of the containment building wake on short-range plume dispersion from the stack must be recognized. Stack effluent will be drawn into the building wake to an extent dependent on meteorological conditions. For example, the top of the stack is nearly within the wake cavity flow for south winds. Hence, stack effluent is more likely to be drawn into the building wake with airflows toward the northwest than towards the southeast. At equal distances northwest and southeast of the plant, ground level concentrations would then be higher northwest. Such differences persist only in approximately the first kilometer from the stack.

During collection of samples one and four, the plume was located near the sampling station about one-half of the time (Table II). Calculated dispersion levels properly exceed the measured values. During tests two and three, the plume centerline apparently remained nearly the sampling location, but the calculated values are low. In general, calculated dispersion levels appear slightly overestimated, probably due to the failure to account for downwash in the wake from the containment building and terrain-induced turbulence. Both factors lead to higher ground level concentrations (lower dispersion levels) at short range than would otherwise occur. Refer to Table III.

6. CONCLUSIONS

The use of a FIDLER for locating the plume from a PWR and converting this measurement to exposure estimates has been shown to be feasible. The maximum exposure rate was 0.14 μR/hr integrated over one 35-minute sampling time and the average over the 2.3-hour positive detection period was 0.086 μR/hr. The exposure rate for the gamma rays from ^{133}Xe is 0.12 μR/hr when normalized for time in the plume only. The highest value for any one sampling period remains the same since during collection of sample number two, readings were obtained on the FIDLER throughout. Since the CYNPP normally releases stored gaseous waste for a total of approximately 24 hours per year, it is evident the external whole-body gamma dose from this plant source presents a negligible exposure to the population offsite. If the 0.12 μR/hr figure is multiplied by 24 (assuming someone to always be in the plume) the whole-body exposure would be about 3 μR/yr. Different meteorological conditions could affect this slightly up or down but for the sake of this discussion this figure is about 30 000 times less than whole body exposure from natural background. The discharge rates of ^{133}Xe released for this study were higher than typical. At normal discharge levels, the ^{133}Xe activity in the field may be marginally detectable with the FIDLER under the meteorological conditions described.

The count rate from the field instrument appears to be useful in estimating the ^{133}Xe concentration under "C" slightly unstable meteorological conditions based on integrated net counts over a period of time. The minimum sensitivity of this procedure appears

to be less than 2 x 10^{-6} μCi/cc of ^{133}Xe which is about a factor of 10 less than the allowable ambient concentrations from the general population (10 CFR-20) [6] on a continuous basis. This should be more rigorously tested at these and other conditions, however.

Calculated dispersion levels reasonably agree with those observed. Differences can probably be explained by the downwash in the wake from the containment buildings and the terrain-induced turbulence. Estimates differed from measurements by a factor of 0.6 to 2.4 (Table III).

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NOTE:

The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products by the U.S. Department of Health, Education, and Welfare or by the Environmental Protection Agency.

APPENDIX

PLUME RISE AND DISPERSION ESTIMATES

Plume rise estimated by ASME technique [7]:

$$\Delta h = d\left(\frac{V_s}{\bar{u}}\right)^{1.4}$$

where

Δh = height of plume centerline above stack height, m

V_s = stack effluent velocity = 13.0 m/sec

$\bar{u}$ = average wind speed, m/sec

d = stack diameter = 1.8m

The dispersion estimates, as suggested by Pasquill and modified by Gifford [5], were obtained by the following equation:

$$X = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp[-1/2(\frac{H}{\sigma_z})^2]$$

where

X = ^{133}Xe concentration at ground on plume centerline, $\mu Ci/m^3$

Q = ^{133}Xe emission rate, $\mu Ci/sec$

σ_y = crosswind plume standard deviation, m

σ_z = vertical plume standard deviation, m

$\bar{u}$ = average wind velocity, m/sec

H = effective stack height, m

The following parameters are used to decermine the calculated dispersion estimates for distance of 0.6 km:

Sample No.	$\bar{u}$ m/sec	Δh, m	σ_y, m	σ_z, m
1	3.2	4	66	38
2	5.0	3	66	38
3	5.8	2	66	38
4	5.4	3	66	38

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